METHODOLOGY AND RESULTS OF THE NEAR-EARTH OBJECT (NEO) HUMAN SPACE FLIGHT (HSF) ACCESSIBLE TARGETS STUDY (NHATS)

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Near-Earth Asteroids (NEAs) have been identified by the current administration as potential destinations for human explorers during the mid-2020s. While the close proximity of these objects' orbits to Earth's orbit creates a risk of highly damaging or catastrophic impacts, it also makes some of these objects particularly accessible to spacecraft departing Earth, and this presents unique opportunities for solar system science and humanity's first ventures beyond cislunar space.

Planning such ambitious missions first requires the selection of potentially accessible targets from the growing population of nearly 7,800 NEAs. To accomplish this, NASA is conducting the Near-Earth Object (NEO) Human Space Flight (HSF) Accessible Targets Study (NHATS). Phase I of the NHATS was executed during September of 2010, and Phase II was completed by early March of 2011. The study is ongoing because previously undetected NEAs are being discovered constantly, which has motivated an effort to automate the analysis algorithms in order to provide continuous monitoring of NEA accessibility.

The NHATS analysis process consists of a trajectory filter and a minimum maximum estimated size criterion. The trajectory filter employs the method of embedded trajectory grids[1] to compute all possible ballistic round-trip mission trajectories to every NEA in the Jet Propulsion Laboratory (JPL) Small-Body Database (SBDB) and stores all solutions that satisfy the trajectory filter criteria. An NEA must offer at least one qualifying trajectory solution to pass the trajectory filter.

The Phase II NHATS filter criteria were purposely chosen to be highly inclusive, requiring Earth departure date between January 1$^{\text{st}}$, 2015 and December 31$^{\text{st}}$, 2040, total round-trip flight time $\leq$ 450 days, stay time at the NEA $\geq$ 8 days, Earth departure C_3 energy $\leq$ 60 km^2/s^2, total mission $\Delta v \leq$ 12 km/s (including an Earth departure maneuver from a 400 km altitude circular parking orbit), and a maximum atmospheric re-entry speed of 12 km/s. After determining which NEAs offer at least one trajectory solution meeting the criteria, the estimated size constraint is then imposed whereby those NEAs may only be considered NHATS-qualifying NEAs if their maximum estimated size is $\geq$ 30 m. This corresponds to an absolute magnitude $H \leq 26.5$ with an assumed albedo $p = 0.05$.

The following is a brief high-level summary of the Phase II study results. Of the 7,665 NEAs in the SBDB as of February 3$^{\text{rd}}$, 2011, 765 NEAs passed the trajectory filter and yielded a total of 79,157,604 trajectory solutions. The trajectory solutions for each NEA are post-processed into Pork Chop Contour (PCC) plots which show total mission Δv as a function of Earth departure date and total mission duration. Although the PCC plots necessarily compress a very multi-dimensional design space into a two-dimensional plot, they permit rapid assessment of the breadth and quality of an NEA's available Earth departure season and clearly indicate the regions of the trajectory design space which warrant further analysis and optimization. The PCC plot for the NEA with the greatest number of NHATS-qualifying trajectory solutions, 2000 SG$_{344}$, is shown in Figure 1.

Of the 765 NEAs which passed the Phase II trajectory filter, a total of 590 NEAs also satisified the further constraint of maximum estimated size $\geq$ 30 m. The distributions of osculating heliocentric orbital semi-major axis (a), eccentricity (e), and inclination (i), for those 590 NEAs are shown in Figures 2(a) and 2(b). Note that the semi-latus rectum used in Figure 2(a) is equal to $a\left(1-e^2\right)$.

To further our understanding of round-trip trajectory accessibility dynamics, it is instructive to examine the distribution of the NHATS-Qualifying NEAs according to orbit classification. NEAs are grouped into four orbit families: Atiras (aphelion $<$ 0.983 AU), Atens (aphelion $>$ 0.983 AU, $a <$ 1.0 AU), Apollos (perihelion $<$ 1.017 AU, $a >$ 1.0 AU), and Amors (1.017 $<$ perihelion $<$ 1.3 AU).

Of the 765 NEAs which satisifed the NHATS trajectory criteria, none are Atiras, 193 are Atens (31% of known Atens), 456 are Apollos (11% of known Apollos), and 116 are Amors (4% of known Amors). While

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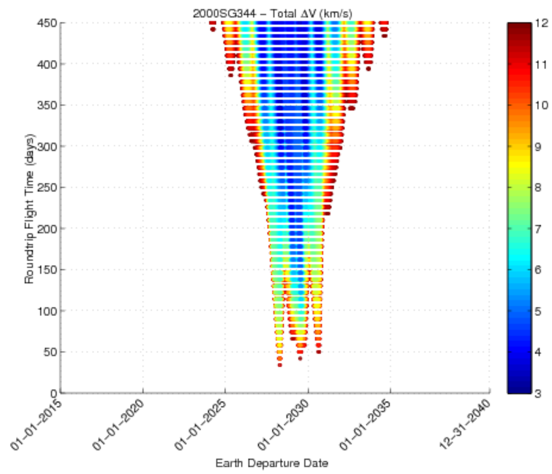
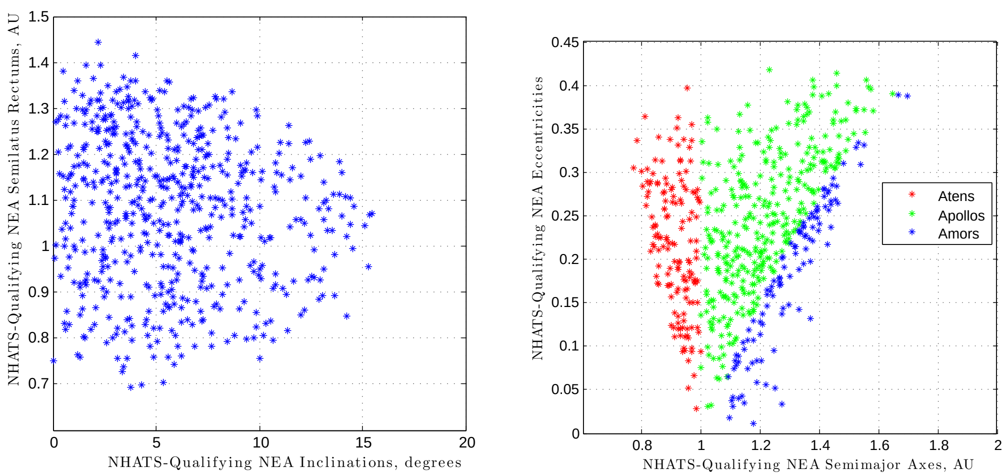


Figure 1. PCC Plot for NEA 2000 SG_{344}



(a) Semi-latus Rectum vs. Inclination

(b) Eccentricity vs. Semi-major Axis

Figure 2. Distribution of the 590 NHATS-Qualifying NEAs in Osculating (a, e, i) Space

Apollos comprise 60% of the NEAs which pass the NHATS trajectory filter and Atens comprise only 25%, the percentages according to orbit family are perhaps more relevant. Note that only 11% of known Apollos passed the trajectory filter while 31% of known Atens passed. These simple statistics alone strongly suggest that Aten orbits possess features which tend to enhance their round-trip trajectory accessibility as compared to Apollos or Amors. This is significant because Atens' orbits cause them to spend considerable time in Earth's daytime sky, making them difficult to discover and track using ground-based observing assets.

In this paper we will detail the NHATS analysis algorithms, present and analyze all NHATS results to date, and discuss aspects of HSF mission architecture design for future NEA missions.

References

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